

BAKERIAN LECTURE.—“The Succession of Changes in Radio-active Bodies.” By E. RUTHERFORD, F.R.S., Macdonald Professor of Physics, McGill University, Montreal. Lecture delivered May 19, 1904.

(Abstract, Received May 27, 1904.)

It has been shown by Rutherford and Soddy that the radio-activity of the radio-elements is always accompanied by the production of a series of new substances, possessing some distinctive physical and chemical properties. These new substances are not produced simultaneously, but arise in consequence of a succession of changes originating in the radio-elements. The radio-activity of these products is not permanent, but diminishes, in most cases according to an exponential law, with the time. Each product has a distinctive rate of decay of activity, which has not, so far, been altered by any physical or chemical agency. The law of decay has been explained on the supposition that the product undergoes change according to the same law as a mono-molecular change in chemistry. The change occurs in consequence of the expulsion of an α or β particle, or both, and the activity of a product is thus a measure of its rate of change. While the products like the emanations, and UrX , lose their activity according to an exponential law, the matter emanation X , which gives rise to the phenomena of excited activity, does not lose its activity according to a simple law. The experiments of Miss Brooks and the author, and of Curie and Danne, have shown that the decay of the excited activity of radium is very complicated, and depends upon the time of exposure to the exciting cause, viz., the emanation. The author has shown that the excited activity produced in a body by a short exposure in the presence of the thorium emanation increases at first for a few hours, passes through a maximum value, and then decays with the time according to an exponential law.

In the paper the curves of decay of excited activity of radium and thorium are given for both short and long exposures to the emanations, and it is shown that the law of change of activity with time can be completely explained on the theory that emanation X of thorium and radium is complex and undergoes a series of successive changes.

The mathematical theory of successive changes is given in detail, and a comparison is made of the theoretical and experimental curves obtained for the variation with time of the excited activity. In the case of thorium, two changes are found to occur in emanation X . The first change is a “rayless” one, *i.e.*, the transformation is not accompanied by the appearance of α , β , or γ rays. The second change gives rise to all three kinds of rays.

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The decay of activity of emanation X of radium depends greatly on whether the α or β rays are used as a means of measurements. The curves obtained by the β rays are always identical with those obtained by the γ rays, showing that the β and γ rays always occur together and in the same proportion. The complicated decay curves obtained for the different types of rays, and for different times of exposure, can be completely explained on the supposition that there are three rapid successive changes in the matter deposited by the emanation, viz. :—

(1) A rapid change, giving rise only to α rays, in which half the matter is transformed in about 3 minutes.

(2) A “rayless” change in which half the matter is transformed in 21 minutes.

(3) A change giving rise to α , β and γ rays together, in which half the matter is transformed in 28 minutes.*

A similar rayless change is shown to occur in the “emanating substance” of Giesel.

The occurrence of a rayless change in the three radio-active bodies is of considerable interest. Since the change is not accompanied by rays, it can only be detected by its effect in the change or changes which follow. The matter of the rayless change is transformed according to the same law as the other changes. The rayless change may be supposed to consist either of a rearrangement of the components of the atom or a disintegration of the atom, in which the products of the disintegration are not set in sufficiently rapid motion to ionise the gas or to affect a photographic plate. The significance of the rayless changes is discussed, and the possibility is pointed out that similar rayless changes may occur in ordinary matter; for the changes taking place in the radio-active bodies would probably not have been detected if a part of the atom had not been expelled with great velocity.

The radiations from the different active products have been examined and it is shown that the β and γ rays appear only in the last rapid change of each of the radio-elements. The other changes are accompanied by the emission of α particles alone.

Evidence is given that the last rapid change in uranium, radium, and thorium, which gives rise to β and γ rays, is far more violent and explosive in character than the preceding changes. There is some evidence for supposing that, in addition to the expelled α and β particles, more than one substance is produced as a result of the disintegration.

* A statement of the nature of the three changes occurring in emanation X of radium was first given in a paper by Rutherford and Barnes (*Phil. Mag.*, Feb., 1904). A brief account of the theory from which the results were deduced has been given in my book “Radioactivity” (Cambridge University Press). Later, Curie and Danne (*Comptes Rendus*, March 14, 1904) arrived, in a similar way, at the same conclusions.

After the three rapid changes have taken place in emanation X of radium, there remains another product, which loses its activity extremely slowly. Mme Curie showed that a body, which had been exposed for some time in the presence of the radium emanation, always manifested a residual activity which did not appreciably diminish in the course of 6 months. A similar result has been obtained by Giesel. Some experiments are described, in which the matter of slow decay, deposited on the walls of a glass tube containing the emanation, was dissolved in acid. The active matter was found to emit both α and β rays, and the latter were present in unusually large proportion. The activity measured by the β rays diminished in the course of 3 months, while the activity measured by the α rays was unaltered. The active matter was complex, for a part which gave out only α rays was removed by placing a bismuth plate in the solution. The radio-active matter deposited on the bismuth is closely allied in chemical and radio-active properties to the active constituent contained in the radio-tellurium of Marckwald. The evidence, as a whole, is strongly in support of the view that the active substance present in radio-tellurium is a disintegration product of the radium atom. Since the radium emanation is known to exist in the atmosphere, the active matter of slow dissipation produced from the emanation must be deposited on the surface of all bodies exposed to the open air. The radio-activity observed in ordinary materials is thus probably, in part, due to a thin surface film of radio-active matter deposited from the atmosphere.

A review is given of methods of calculation of the magnitude of the changes occurring in the radio-elements. It is shown that the amount of energy liberated in each radio-active change, which is accompanied by the emission of α particles, is about 100,000 times as great as the energy liberated by the union of hydrogen and oxygen to form an equal weight of water. This energy is, for the most part, carried off in the form of kinetic energy by the α particles.

A description is given of some experiments to see if the α rays carried a positive charge of electricity, with the view of experimentally determining the number of α particles projected from one gramme of radium per second. Not the slightest evidence was obtained that the α rays carried a charge at all, although it should readily have been detected. Since there is no doubt that the α rays are deflected in magnetic and electric fields as if they carried a positive charge, it seems probable that the α particles must in some way gain a positive charge after their expulsion from the atom.

Since on the disintegration theory, the average life of a given quantity of radium cannot be more than a few thousand years, it is necessary to suppose that radium is being continuously produced in the earth. The simplest hypothesis to make is that radium is a disintegration

product of the slowly changing elements uranium, thorium, or actinium present in pitchblende. It was arranged that Mr. Soddy should examine whether radium is produced from uranium, but the results so far obtained have been negative.

I have taken solutions of thorium nitrate and the "emanating substance" of Giesel (probably identical with the actinium of Debierne) freed from radium by chemical treatment, and placed them in closed vessels. The amount of radium present is experimentally determined by drawing off the emanation at regular intervals into an electroscope. A sufficient interval of time has not yet elapsed to settle with certainty whether radium is being produced or not, but the indications so far obtained are of a promising character.

"On the Electric Equilibrium of the Sun." By SVANTE ARRHENIUS.

Communicated by Sir WILLIAM HUGGINS, Pres. R.S. Received and read June 2, 1904.

In recent years many attempts have been made to apply the pressure of radiation, that is a consequence of the theories of Maxwell and Bartoli, to the explanation of cosmical phenomena. Especially the enigma of the nature of comets' tails has been elucidated from this new point of view.

In a memoir presented to the Swedish Academy of Sciences in 1899, I pointed out that several electric and magnetic phenomena, especially auroras and magnetic storms, might also be connected with the pressure of radiation. C. T. R. Wilson found that the negative ions condense vapours more easily than do positive ions. Without doubt the gases in the atmosphere of the sun are practically ionised by the ultra-violet radiation. Therefore we have to suppose, that among the little drops formed by condensation in the sun's atmosphere far more are negatively charged than are positively charged. As these drops are driven away by the pressure of radiation they charge with negative electricity the atmospheres of celestial bodies, *e.g.*, the earth, which they meet, till the charge is so great that discharges occur, and cathode rays are formed, which carry the charge back to the universe.

A calculation of the speed, with which these particles move through space, will not be without interest. Suppose first, for simplicity, that the pressure of radiation is double that of the weight of the particles in the neighbourhood of the sun. It is not difficult to calculate, that in this case the time, necessary for the particle's passage from the surface of the sun to the earth, amounts to 68.7 hours. The specific weight is supposed to be that of water.

Now, after Schwarzschild's calculations, a perfectly reflecting drop